The Structure and the Distance of Collinder 121 from *Hipparcos* and Photometry: Resolving the Discrepancy

Nadia Kaltcheva

Department of Physics and Astronomy, University of Wisconsin Oshkosh, 800 Algoma Blvd., Oshkosh, WI 54901

kaltchev@uwosh.edu

and

Valeri Makarov

Michelson Science Center, California Institute of Technology, 770 S. Wilson Ave., MS 100-22, Pasadena, CA 91125

vvm@caltech.edu

ABSTRACT

We present further arguments that the *Hipparcos* parallaxes for some of the clusters and associations represented in the *Hipparcos* catalog should be used with caution in the study of the Galactic structure. It has been already shown that the discrepancy between the *Hipparcos* and ground based parallaxes for several clusters including the Pleiades, Coma Ber and NGC 6231 can be resolved by recomputing the *Hipparcos* astrometric solutions with an improved algorithm diminishing correlated errors in the attitude parameters. Here we present new parallaxes obtained with this algorithm for another group of stars with discrepant data - the galactic cluster Cr 121. The original *Hipparcos* parallaxes led de Zeeuw et al. to conclude that Cr 121 and the surrounding association of OB stars form a relatively compact and coherent moving group at a distance of $\simeq 550-600$ pc. Our corrected parallaxes reveal a different spatial distribution of young stellar populace in this area. Both the cluster Cr 121 and the extended OB association are considerably more distant ($750-1000$ pc), and the latter has a large depth probably extending beyond 1 kpc. Therefore, not only are the recalculated parallaxes in complete agreement with the photometric $uvby\beta$ parallaxes, but the structure of the field they reveal is no longer in discrepancy with that found by the photometric method.

Subject headings: stars : distances — open clusters and associations : individual (Collinder 121)— Galaxy : structure

1. Introduction

Obtaining reliable knowledge about the structure and distance of nearby OB associations plays a critical role in the overall study of the Milky Way morphology near the Sun. Unlike the external galaxies where the star-forming fields are generally evident from direct imaging, the study of the spiral structure of our own Galaxy is largely grounded in distance determinations of young stellar tracers. At present, sufficiently accurate astrometric data (parallaxes and proper motions) are available for few star-forming regions within $\simeq$ 500 pc. More comprehensive and representative studies of the local history and dynamics of star formation have to rely on the photometric method of distance determination and stellar evolution theory.

The completion of the *Hipparcos* catalog (ESA 1997) offered a possibility for a major improvement of the membership of young moving groups near the Sun and refining the distance scale to nearby open clusters and OB associations. However, the mean *Hipparcos* parallaxes for some galactic clusters are in disagreement with ground-based determinations by various methods. Statistically significant discrepancies between the *Hipparcos* trigonometric and traditional photometric, spectroscopic and interferometric results have been reported in the literature for selected small-scale fields, most notably for the Pleiades open cluster (Pinsonneault et al. 1998, Soderblom et al. 1998, Narayanan & Gould 1999, Stello & Nissen 2001, Makarov 2002, Pan et al. 2004, Percival et al. 2005, Soderblom et al. 2005). Platais et al. (2007) found a similar offset in the *Hipparcos* mean parallax for the young open cluster IC 2391. A discrepancy was reported by Kaltcheva et al. (2005) for the open cluster IC 2602 as well. The cause for these inconsistencies is most likely due to a faulty data reduction algorithm used in *Hipparcos*, which allowed highly correlated errors of along-scan attitude parameters to propagate into the fitted astrometric parameters. An alternative data reduction approach has been suggested and successfully tested by Makarov (2002, 2003).

The region of Cr 121 is another example of this discrepancy. Since the discovery of a compact group at ℓ, b= (234.98°, −10.21°) by Collinder (1931), both the cluster and the larger 10° x 10° field have been extensively studied by UBV and $uvby\beta$ photometry. This area includes one of the 12 OB associations within 1 kpc from the Sun with fairly detailed kinematical information and membership determined from *Hipparcos*. The *Hipparcos* proper motions reveal a moving group of 103 stars between $\ell = 227°$ and $\ell = 245°$, identifying the compact cluster Cr 121 with an unbound extended OB association at a distance of 592±28

pc, similar to Sco OB2 (de Zeeuw et al. 1999). Robichon et al. (1999) selected 13 *Hipparcos* members of Cr 121 and found a mean *Hipparcos* parallax of 1.80±0.24 mas (556 ± 74 pc). In contrast to these results from *Hipparcos*, the latest $uvby\beta$ photometric study (Kaltcheva 2000) concluded that a compact stellar group apparently identical to the genuine cluster (Cr 121) is situated at 1085±41 pc and the closest members of the loose association are found at an average distance of 660-730 pc, in agreement with most of the previous photometric investigations. Since the $uvby\beta$ photometry is arguably the best photometric system in use to provide accurate photometric distances, the origin of the discrepancy was suggested to be in the *Hipparcos* parallaxes for the Cr 121 members. Burningham et al. (2003) studied the low-mass pre-main sequence stars toward Cr 121 and also came to conclusions consistent with the photometric distance determinations.

In this letter, we consider a sample of probable members of the extended association around Cr 121 selected by de Zeeuw et al. (1999) for which accurate $uvby\beta$ photometry is available. The astrometric parameters of these stars are recomputed from the *Hipparcos* Intermediate Astrometry Data by the method proposed by Makarov (2002). The recomputed parallaxes allow us to resolve the controversy about the distance and dimensions of the OB association in this field.

2. Results and Discussion

Our sample contains all 44 early-type stars with *Hipparcos* parallaxes listed by de Zeeuw et al. (1999) as probable members of the Cr 121 moving group for which $uvby\beta$ photometry is available. Homogeneous photometric $uvby\beta$ distances are calculated for 43 of them (Kaltcheva 2000). Table 1 presents the sample, where the *Hipparcos* identification numbers are given in the first column, followed by the *Hipparcos* parallaxes and their errors, recalculated parallaxes and their errors, photometric $uvby\beta$ distances and MK spectral classification. The stars are formally divided into field stars (or possible association members), spread over a $10^\circ \times 10^\circ$ area around the center of Cr 121 and 6 photometrically selected members of the dense cluster Cr 121 (Kaltcheva 2000 and references therein). As follows from the data in Table 1 there is a statistically significant difference between the mean *Hipparcos* parallax of 1.87 ± 0.15 mas and the mean recomputed parallax of 1.29 ± 0.15 mas. The errors provided here are the formal standard deviation of the mean computed from the formal errors of parallaxes.

Fig. 1 shows the original *Hipparcos* parallaxes (left plot) and our recomputed parallaxes (right plot) versus the photometric parallaxes for the sample of 43 stars in Table 1. The *Hipparcos* parallaxes are on average larger than the photometric values by 0.52±0.107 mas,

where the quoted error is the sample standard error of the mean. This is a statistically significant difference of the same order as those found for the Pleiades and a few other Galactic clusters. On the other hand, the agreement is excellent between the mean photometric parallax and the mean corrected parallax (0.063 ± 0.158 mas). This supports our main conclusion that the *Hipparcos* parallaxes are systematically overestimated in this area of the sky. But Fig. 1 also reveals another strange property of the original parallaxes. While the recomputed parallaxes are scattered fairly symmetrically around the line of unit slope in the right plot and their dispersion is in good agreement with the measurement errors, the original parallaxes are grouped tightly around the mean (1.87 mas) with a standard deviation of only 0.61 mas. This value is much too small for the estimated formal errors (mean 0.93 mas, *rms* 0.96 mas). We attribute this result to a strong selection effect in the method employed by de Zeeuw et al. (1999), which preferentially accepted stars with large measured parallaxes, i.e., mostly stars with positive errors "observed minus true". In combination with the correlated error of the mean parallax, this selection bias gives rise to doubt about the completeness and reliability of the present membership list.

The significant dispersion of both photometric and recomputed parallaxes also implies a complex morphology of this moving group having a considerable depth, as opposed to the previous conjecture of an association compressed in the radial dimension, similar to the nearby Sco OB2 association, as concluded by de Zeeuw et al. (1999). The group also appears to be located at a larger distance of $\simeq 740$ pc, rather than at $\simeq 550$ pc as follows from the mean *Hipparcos* parallax of the sample in Table 1. Based on a larger photometric sample it has already been pointed out that the loose nearby structure defined by de Zeeuw et al. (1999) to be located at 592±28 pc photometrically appears to be more distant by about 100 pc (Kaltcheva 2000). The parallaxes recalculated here support the photometric findings.

Our result implies that the problem of inaccurate mean parallaxes in *Hipparcos* affects more regions, and of larger angular area, than just a few small patches occupied by dense open clusters. This is not an irreversible situation, because the method of astrometric solution of the available *Hipparcos* data used in this paper proves once again successful in correcting this error, despite its limitations. A more systematic and thorough comparison of *Hipparcos* data with distances from precision multi-band photometry will probably reveal more problematic areas. It is not clear at present how widely spread the parallax error is, and whether a global astrometric solution will have a significant impact on the present knowledge of distances and morphology for many of the OB associations represented in the catalog, but it is evident that the *Hipparcos*-based census of some of the moving groups near the Sun should be critically reconsidered.

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Table 1: The sample: identifications from the *Hipparcos* catalog, followed by the *Hipparcos* parallaxes π and their formal errors σ_π, the recalculated parallaxes π_r and their formal errors σ_{π_r}, the photometric $uvby\beta$ distances r and the MK classification.

HIP	π (mas)	σ_π (mas)	π_r (mas)	σ_{π_r} (mas)	r (pc)	MK
Field stars						
31436	1.14	0.90	0.67	0.94	1812	B2/B3V
31901	2.05	1.06	0.95	1.07	1050	B5
32084	2.63	1.18	-1.02	1.09	664	B3V
32101	1.24	1.07	-0.21	1.11	938	B9.5III
32591	1.42	0.97	0.14	0.98	605	B8V
33007	1.16	0.86	1.17	0.92	475	B4V
33092	2.02	0.70	2.37	0.78	518	B1Ib
33165	1.74	0.76	1.33	0.85	-	WN...
33260	1.19	1.10	0.98	1.11	930	B9Ib/II
33294	1.43	0.69	0.82	0.77	681	B2III/IV
33316	1.51	0.64	-0.32	0.73	632	B2/B3III
33447	2.78	0.70	1.23	0.77	766	B2III/IV
33523	1.70	1.23	-0.41	1.25	1697	B2V
33532	2.24	0.73	1.04	0.85	539	B2.5III
33611	2.05	0.70	1.40	0.76	722	B2V
33621	1.70	0.93	0.29	0.98	764	B8II/III
33666	2.33	0.68	0.90	0.76	740	B2III
33673	1.68	0.72	0.56	0.78	923	B4Vn
33721	2.46	0.74	1.43	0.81	706	B3Vnn
33769	1.26	0.80	0.25	0.85	1077	B2/B3V
33770	2.05	0.97	1.31	1.28	630	B2IV
33804	3.17	0.59	3.29	0.66	365	B2/B3III/IV
33814	2.31	0.93	2.44	0.97	887	B3V
33846	1.41	0.74	2.04	0.80	647	B3V
33865	1.75	1.18	-0.14	1.35	648	B3IV
33888	1.35	1.13	1.38	1.14	793	B9V+...
34041	1.79	0.66	1.48	0.72	521	B2/B3V
34067	1.66	0.80	2.27	0.84	853	B3III
34074	1.10	1.10	1.82	1.13	1597	B7/B8III
34153	2.55	1.06	1.92	1.09	535	B8V
34167	1.44	0.91	1.45	0.94	958	B2IV
34219	1.95	1.67	2.94	1.38	665	B6III
34227	1.04	0.94	0.90	0.97	757	B3V:n
34281	1.28	1.03	1.16	1.04	842	B5V
34331	2.23	0.65	1.11	0.71	534	B2IV-V
34579	1.78	0.60	1.64	0.68	368	B2V
34940	2.07	1.24	3.18	0.98	676	B2IV
35026	1.44	0.78	2.34	0.83	1435	B2IV/V
Cr 121						
32823	1.92	1.23	2.41	1.26	944	B5V
32911	3.49	1.02	2.75	1.05	1012	B8IV/V
33062	1.22	0.96	0.81	1.02	947	B2II/III
33070	2.30	1.13	0.97	1.17	1291	B3II/III
33208	1.77	1.14	1.16	1.16	981	B3V
33211	3.46	1.08	2.51	1.11	1131	B3V

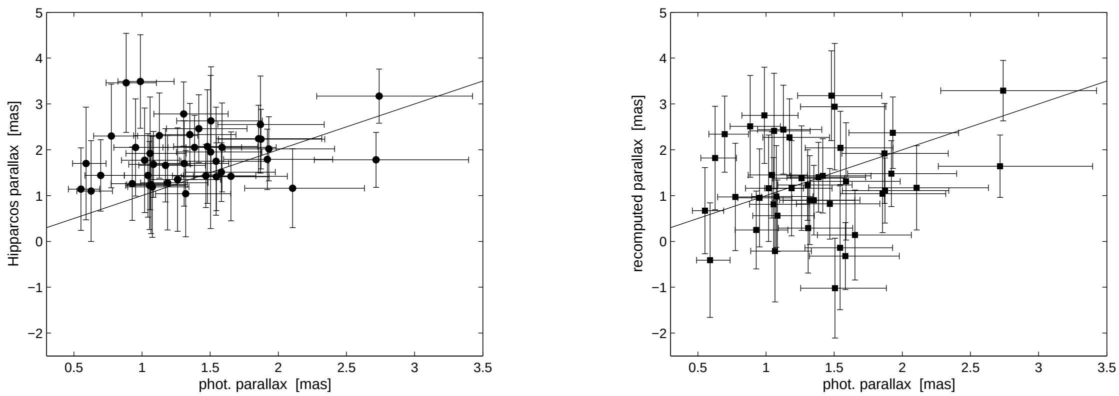

Fig. 1.— Differences between the *uvbyβ* photometric parallaxes and *Hipparcos* parallaxes (left plot), and the parallaxes recomputed in this paper (right plot) for stars in the area of Cr 121. The error bars of the photometric parallaxes correspond to the maximum estimated error in the photometric distances of 20 %.

We are grateful to the referee Dr. R. Hanson for a number of valuable comments. A UW Oshkosh Vander Putten Award is acknowledged. The research described in this paper was in part carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.